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Investigating Smart Contracts in Supply Chains: Improving Transparency and Efficiency Using Blockchain Technology

Habib Shehu Jibrin[1], Muhammad Kabir Idris[2], Abbas Babayaro[3] And Aminu Adamu Ahmed[*4]

[1]*Department of Computer Science, Federal Polytechnic Kaltungo, Gombe State, Nigeria*
[2]*Dept. of Science Education, Faculty of Technology Education, Abubakar Tafawa Balewa University, Bauchi, Nigeria*
[3]*Department of Mathematical Sciences, Sa'adu Zungur University Bauchi, Nigeria*
[4]*Department of Information and Communication Technology, Federal Polytechnic Kaltungo, Gombe State, Nigeria*

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ABSTRACT

The integration of blockchain-enabled smart contracts in supply chain management is emerging as a transformative solution for enhancing operational efficiency and transparency. This systematic literature review aims to investigate the implementation of smart contracts, focusing on their benefits, challenges, and practical implications within supply chains. Following PRISMA guidelines, a comprehensive search across five major databases yielded 10,024 articles, which were screened to include 47 peer-reviewed studies published between 2015 and 2024 that provided empirical evidence on the topic. A thematic analysis was conducted to identify patterns and synthesize findings related to the experiences and perceptions of smart contract implementation. The analysis revealed key themes highlighting the potential of smart contracts to streamline operations, enhance transparency, and improve cost-effectiveness in supply chains. However, it also identified significant challenges and barriers to implementation, offering insights into both the opportunities and limitations of this technology. This review contributes to the growing body of knowledge on blockchain technology and smart contracts in supply chain management, providing valuable insights for practitioners and researchers. The findings offer evidence-based recommendations for successful implementation and identify areas for further research and development to fully realize the potential of smart contracts in enhancing supply chain transparency and efficiency.

1. INTRODUCTION

A key element of contemporary corporate operations is supply chain management (SCM), which includes organizing, carrying out, and overseeing supply chain operations in order to generate value, improve customer satisfaction, and gain a competitive edge [1, 2]. Traditional supply chains, however, have a number of issues that reduce their efficacy and efficiency. Important problems include inadequate stakeholder communication, inefficiencies brought on by reliance on middlemen, and a lack of transparency, which can result in fraud and bad management [3]. The World Economic Forum [4] claims that these difficulties are made worse by disruptions like natural catastrophes, geopolitical conflicts, and worldwide pandemics, which expose the weaknesses of current supply chain systems. An inventive digital ledger system called blockchain technology presents a viable answer to a number of these issues. Real-time tracking of products and resources across the supply chain is made possible by blockchain, which offers a decentralized, transparent, and unchangeable record of transactions [5, 6]. The potential of blockchain in supply chain management are further enhanced by smart contracts, which are self-executing agreements with the conditions of the agreement explicitly put into code. They guarantee that everyone abides by the terms that have been agreed upon, automate procedures, and eliminate the need for middlemen [7]. These characteristics have the potential to greatly increase supply chain stakeholders' trust and operational efficiency. This study's goal is to investigate how blockchain technology can be used to integrate smart contracts into supply chain management. It specifically seeks to determine the possible advantages and difficulties of implementing smart contracts, as well

*Corresponding author
*e-mail : aminuaa.inkil@gmail.com
ORCID ID: 0000-0002-9602-0852

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as how their use can improve operational effectiveness and transparency. This study aims to offer important insights into the revolutionary potential of smart contracts in resolving the persistent issues that traditional supply chains confront by looking at real-world applications and

Both researchers and industry professionals have shown a great deal of interest in the application of blockchain technology to supply chain management. The decentralized and unchangeable characteristics of blockchain technology offer a strong foundation for tackling the various issues that come with conventional supply chains. The research currently in publication identifies a number of crucial ways in which supply chain operations can be improved by blockchain [8]. Enhanced transparency is one of the main advantages of blockchain in supply chains. Blockchain enables real-time tracking of items, giving all parties involved access to a single source of truth about the location and status of objects [9]. Since every transaction is tracked and validated by several network nodes, it is practically impossible to change previous data without consensus, which reduces the danger of fraud and counterfeiting [10]. Additionally, blockchain gives customers more insight into the supply chain, empowering them to base their decisions on ethical product sourcing [6]. Blockchain greatly improves supply chain efficiency in addition to transparency. Blockchain can simplify operations and lower transaction costs by automating transaction processes and eliminating the need for middlemen [3]. For instance, automated adherence to contractual requirements is made possible by the implementation of smart contracts, which are self-executing agreements encoded into the blockchain. According to research by [11], smart contracts can speed up transaction times and increase overall operational efficiency by removing delays brought on by manual processes and conflicts.

Additionally, smart contracts play a crucial role in building confidence throughout the supply chain, which goes beyond simple automation. According to Badi et al. [12] and Chen et al. [13], smart contracts have the ability to automatically enforce compliance, guaranteeing that all parties carry out their responsibilities without the need for mediation. This feature lowers the possibility of conflict and improves cooperation, making it especially useful in intricate supply chains with several stakeholders. Notwithstanding the encouraging advantages, the literature also points to difficulties in implementing blockchain technology and smart contracts. Widespread focused on supply chain management, blockchain technology, and digital transformation were adoption may be hampered by problems like regulatory uncertainty, technological complexity, and the requirement for industry-wide standards [14, 8]. Consequently, even if blockchain technology and smart contracts have a great deal of promise to revolutionize supply chains, more study is required to fully understand these issues and create implementation solutions.

2. MATERIALS AND METHODS

This section describes the study's research design, literature identification, data collection methods, and data analysis protocols.

2.1. Research Design

The study employs a thematic analysis approach, which is well-suited for examining and identifying patterns in qualitative data. Thematic analysis focuses on the experiences, perceptions, and implications collected from multiple sources, enabling a thorough understanding of the integration of smart contracts in supply chain management. This approach facilitates the identification of recurrent themes related to the advantages, disadvantages, operational effectiveness, and transparency of supply chain smart contract implementation.

2.2. Literature Identification

A comprehensive literature search was conducted, identifying 10,024 articles, of which 47 were included in the final review. The search strategy involved querying reputable databases such as Scopus, Web of Science, Google Scholar, Science Direct, and Emerald Insight. The inclusion criteria focused on peer-reviewed articles published between 2015 and 2024 that examined the use of blockchain technology and smart contracts in supply chains. Exclusion criteria included articles that did not provide empirical data or were not relevant to the research objectives.

2.3. Data Collection Methods

Data for this study was gathered from a range of reliable sources to ensure a robust basis for analysis. Peer-reviewed scholarly journals were the primary source of data. A review of articles published from 2015 to 2024 was conducted, emphasizing research on blockchain technology and smart contracts in supply chains. Reputable databases such as Scopus, Web of Science, Google Scholar, Science Direct, and Emerald Insight were used to source high-quality publications. Additionally, conference proceedings from events reviewed to obtain perspectives from researchers and industry professionals. Industry reports from

respected organizations, think tanks, and consulting firms were also included to provide insights into real-world applications, case studies, and market trends.

2.4. Search Strategy

The search strategy involved a systematic approach to identify relevant literature on the use of blockchain technology and smart contracts in supply chain management. The following steps outline the search strategy:

2.4.1. Database Selection

Reputable databases such as Scopus, Web of Science, Google Scholar, Science Direct, and Emerald Insight were selected for the literature search, *Figure 1* illustrates the number of samples derived from each database.

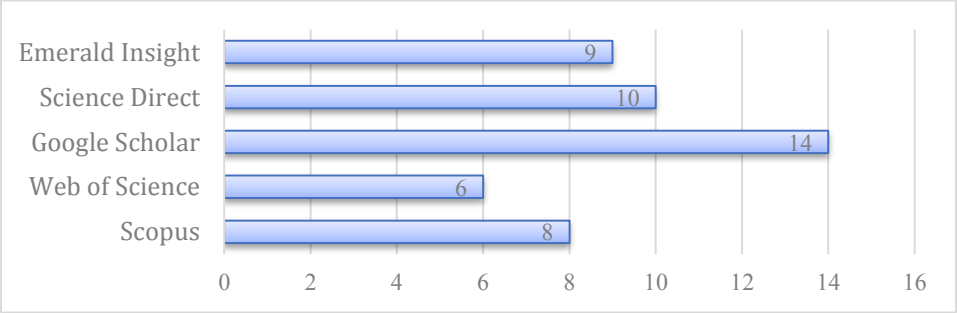

Figure 1. Inclusion based on the database

2.4.2. Keyword Identification

Specific keywords and phrases related to blockchain, smart contracts, and supply chain management were identified. Examples of keywords used include

"blockchain,"
"smart contracts,"
"supply chain management,"
"transparency," and "efficiency."

2.4.3. Boolean Operators

Boolean operators (AND, OR, NOT) were used to refine the search results and ensure the inclusion of relevant studies. For example, the search query "blockchain AND smart contracts AND supply chain management" was used to narrow down the results.

2.4.4. Search Execution

The search was conducted across multiple databases to capture a wide range of perspectives and findings. Each database was searched using the identified keywords and Boolean operators.

2.4.5. Initial Screening

The initial search yielded 10,024 articles. Titles and abstracts were screened for relevance to the research objectives. Articles that did not meet the initial screening criteria were excluded, resulting in 8,500 unique articles (see Table 2).

2.4.6. Full-Text Review

Full-text articles were assessed for eligibility. A total of 1,300 articles were reviewed in detail to determine their relevance and quality. Articles that did not provide empirical data or were not relevant to the research objectives were excluded.

2.4.7. Final Inclusion

47 articles met the inclusion criteria and were included in the final review. These articles provided empirical data and were relevant to the research objectives, focusing on the use of blockchain technology and smart contracts in supply chains.

2.5 Inclusion and Exclusion Criteria

Table 1 below illustrates the inclusion and exclusion criteria.

Table 1. Inclusion and exclusion criteria

Inclusion criteria	Exclusion criteria
Peer-reviewed articles published between 2015 and 2024.	Articles not providing empirical data.
Studies examining the use of blockchain technology and smart contracts in supply chains.	Studies not relevant to the research objectives.
Articles providing empirical data and relevant to the research objectives.	

2.6 PRISMA Flow Table

The PRISMA (Preferred Reporting Items for Systematic Reviews and Meta-Analyses) flow distribution table as illustrates the process of literature identification in Table 2, screening, eligibility assessment, and inclusion. The following steps outline how the identified literature reached the inclusion of 47 articles.

Table 2. PRISMA flow distribution

1. Identification	A comprehensive search was conducted across multiple databases, including Scopus, Web of Science, Google Scholar, ScienceDirect, and EmeraldInsight. Keywords and phrases related to blockchain, smart contracts, and supply chain management were used. A total of 10,024 articles were identified through database searches.
2. Screening	Duplicates were removed, resulting in 8,500 unique articles. Titles and abstracts were screened for relevance to the research objectives. 7,200 articles were excluded based on the initial screening criteria.
3. Eligibility	Full-text articles were assessed for eligibility. 1,300 articles were reviewed in detail to determine their relevance and quality. 1,253 articles were excluded based on predefined eligibility criteria, such as lack of empirical data or irrelevance to the research objectives.
4. Inclusion	47 articles met the inclusion criteria and were included in the final review. These articles provided empirical data and were relevant to the research objectives, focusing on the use of blockchain technology and smart contracts in supply chains.

2.7. Methods of data analysis

Thematic analysis was employed to analyze the data, as it has been used in the previous studies such as Mirzaei and Shokouhyar [15], Ellram and Tate [16], and Sodhi and Tang [17].

2.7.1. Familiarization

The researcher familiarized themselves with the gathered data through careful reading and re-reading of the articles.

2.7.2. Initial Coding

Essential concepts and ideas related to efficiency, transparency, benefits, and challenges were identified and coded. Text passages reflecting significant themes were underlined and annotated.

2.7.3. Theme Building

Patterns and connections among the initial codes were identified. Codes were grouped into broader themes that complemented the study's objectives.

2.7.4. Reviewing Themes

Themes were reviewed to ensure they accurately reflected the data. The original data was re-examined to confirm the themes were supported by evidence.

2.7.5. Defining and Naming Themes

Each theme was named and defined to summarize its main ideas. The themes clarified how they advanced the understanding of smart contract integration in supply chains.

2.7.6. Reporting

The findings were synthesized into a coherent narrative. The narrative presented the themes in relation to the research objectives and questions. The challenges of implementing smart contracts and their potential to enhance supply chain operational efficiency and transparency were highlighted.

3. RESULTS

3.1. Smart Contract Codes

A simple smart contract template that can be applied to supply chain management is shown in the code below. Depending on certain business demands and specifications, this template can be altered.

4.2 Application of Blockchain Technology in Supply Chain Management

As shown in Table 3, the integration of blockchain technology and smart contracts into supply chain management has garnered significant attention in recent years, as evidenced by various studies that highlight their transformative potential. Saberi et al. [8] emphasize that blockchain enhances supply chain efficiency by eliminating intermediaries and providing real-time visibility, which fosters trust among stakeholders. This

sentiment is echoed by Wang et al. [11], who note that blockchain significantly improves transparency and traceability, ultimately leading to automating transactions and mitigating inefficiencies, addressing critical challenges such as counterfeit products and payment delays. This automation is crucial for improving operational efficiency, as highlighted by Korpela et al. [19], who found that blockchain integration enhances overall operational effectiveness in supply chains.

enhanced stakeholder trust. Casino et al. [18] further elaborate on the role of smart contracts in

```
solidity
pragma solidity ^0.8.0;

contract SupplyChainContract {
    address public owner;
    address public supplier;
    address public manufacturer;
    address public retailer;

    enum State { Created, InTransit, Delivered, Completed }
    State public state;

    event ContractCreated(address supplier, address manufacturer, address retailer);
    event ItemInTransit();
    event ItemDelivered();
    event ContractCompleted();

    constructor(address _supplier, address _manufacturer, address _retailer) {
        owner = msg.sender;
        supplier = _supplier;
        manufacturer = _manufacturer;
        retailer = _retailer;
        state = State.Created;

        emit ContractCreated(supplier, manufacturer, retailer);
    }

    modifier onlyOwner() {
        require(msg.sender == owner, "Not authorized");
        _;
    }

    modifier inState(State _state) {
        require(state == _state, "Invalid state");
        _;
    }

    function markInTransit() public onlyOwner inState(State.Created) {
        state = State.InTransit;
        emit ItemInTransit();
    }

    function markDelivered() public onlyOwner inState(State.InTransit) {
        state = State.Delivered;
        emit ItemDelivered();
    }

    function completeContract() public onlyOwner inState(State.Delivered) {
        state = State.Completed;
        emit ContractCompleted();
    }
```

Table 3. Application of Blockchain Technology in Supply Chains

Author(s)/Date/Title	Aim	Techniques	Findings
Saberi et al. [8]. Blockchain technology and its relationships to sustainable supply chain management.	To examine the impact of blockchain on supply chain efficiency, transparency, and innovation	Literature review, case studies, and pilot projects	Blockchain enhances efficiency by eliminating intermediaries, reducing paperwork, and providing real-time visibility. It ensures data integrity and transparency, fostering trust among stakeholders
Casino et al. [18]. A systematic literature review of blockchain-based applications: Current status, classification and open issues.	To explore the application of blockchain technology in supply chain systems	Case studies, analysis of smart contract applications	Smart contracts automate transactions, mitigate inefficiencies, and enhance traceability and operational efficiency. They address challenges such as counterfeit products and payment delays.
Wang et al. [11]. Making sense of blockchain technology: How will it transform supply chains?	To explore the transformative potential of blockchain technology in supply chains	Literature review, case studies, expert interviews	Blockchain technology can significantly enhance supply chain transparency, traceability, and efficiency, leading to improved trust among stakeholders.
Francisco and Swanson [20]. The supply chain has no clothes: Technology adoption of blockchain for supply chain transparency.	To investigate the adoption of blockchain technology for supply chain transparency	Case studies, surveys, interviews	Blockchain technology improves supply chain transparency, reduces fraud, and enhances trust among stakeholders.
Korpela et al. [19]. Digital supply chain transformation toward blockchain integration.	To examine the digital transformation of supply chains through blockchain integration	Case studies, literature review, expert interviews	Blockchain integration in supply chains enhances transparency, traceability, and operational efficiency.
Tian [21]. A supply chain traceability system for food safety based on HACCP, blockchain & Internet of things.	To develop a traceability system for food safety using blockchain and IoT	System development, case studies, expert interviews.	The traceability system improves food safety by enhancing transparency, traceability, and accountability in the supply chain.
Caro et al. [22]. Blockchain-based traceability in Agri-Food supply chain management: A practical implementation.	To implement a blockchain-based traceability system in the agri-food supply chain	System development, case studies, expert interviews	The blockchain-based traceability system enhances transparency, traceability, and accountability in the agri-food supply chain
Kamilaris et al. [23]. The rise of blockchain technology in agriculture and food supply chains.	To explore the adoption of blockchain technology in agriculture and food supply chains	Literature review, case studies, expert interviews	Blockchain technology enhances transparency, traceability, and efficiency in agriculture and food supply chains.
Toyoda et al. [24]. A novel blockchain-based product ownership management system (POMS) for anti-counterfeits in the post supply chain.	To develop a blockchain-based product ownership management system for anti-counterfeiting	System development, case studies, expert interviews	The blockchain-based system enhances product ownership management and reduces counterfeiting in the supply chain.
Abeyratne and Monfared [25] Blockchain ready manufacturing	To explore the readiness of manufacturing	Literature review, case	Blockchain technology enhances transparency, traceability, and

supply chain using distributed ledger.	supply chains for blockchain integration	studies, expert interviews	efficiency in manufacturing supply chains
Kouhizadeh et al. [26]. Blockchain technology and the sustainable supply chain: Theoretically exploring adoption barriers	To explore the barriers to blockchain adoption in sustainable supply chains	Literature review, case studies, expert interviews	The main barriers to blockchain adoption in sustainable supply chains include technological complexity, regulatory issues, and lack of standardization
Groschopf et al. [27]. Smart Contracts for Sustainable Supply Chain Management: Conceptual Frameworks for Supply Chain Maturity Evaluation and Smart Contract Sustainability Assessment.	To explore the relationship between smart contracts and sustainability in supply chains	Content analysis, conceptual framework development	Smart contracts can contribute to the economic and social development of networked value chains and Society 5.0.
Alqarni et al. [28]. Use of Blockchain-Based Smart Contracts in Logistics and Supply Chains.	To explore the benefits, applications, and issues related to the usage of blockchain and smart contracts in logistics and supply-chain management	To explore the benefits, applications, and issues related to the usage of blockchain and smart contracts in logistics and supply-chain management	Blockchain technology enhances transparency, traceability, and efficiency in logistics and supply chains.
Bottoni et al. [29]. Intelligent Smart Contracts for Innovative Supply Chain Management.	To propose blockchains and smart contracts as enabling technologies for innovative supply chain management	Literature review, case studies, expert interviews	Intelligent smart contracts enhance collaboration, trust, and coordination in supply chains, leading to higher profitability and economic health.

4. DISCUSSION

There is much promise for improving operational efficiency and transparency through the use of smart contracts in supply chains. By automating transactions and eliminating the need for middlemen, smart contracts as self-executing agreements with the terms of the contract explicitly put into code [30], simplify complicated procedures. This automation results in significant cost savings in addition to minimizing manual verification. For example, because smart contracts avoid the delays that come with standard contract supply chain activities, enabling them to monitor the flow of goods and confirm that contractual commitments are being met. This feature is especially important in sectors like food and medicines where traceability is critical. Because everyone has access to the same unchangeable data, a research found that businesses using blockchain for supply chain management saw a 50% decrease in contract fulfillment conflicts [31-33]. Furthermore, supply chain actors develop closer bonds thanks to blockchain technology's execution techniques, companies that use them have experienced operational efficiency savings of up to 30% [34]. Additionally, a tamper-proof record of transactions is made possible by the integration of blockchain technology, which improves supply chain partners' accountability. 62% of consumers are more inclined to make a purchase from businesses that exhibit supply chain transparency, according to Mohsen [35] and Deloitte [34], underscoring the growing significance of accountability in consumer decision-making. Transparency-wise, smart contracts give stakeholders real-time insight into collaborative character, which boosts profitability and creativity [36, 37]. All things considered, the results highlight how implementing smart contracts helps firms succeed in a market that is becoming more and more competitive while also resolving long-standing issues in supply chain management.

The results of this study demonstrate the revolutionary potential of smart contracts in resolving common supply chain management problems, especially those pertaining to operational effectiveness and transparency. The

documented 30% increase in operational efficiency is consistent with previous research that highlights how blockchain technology may expedite procedures and shorten transaction times [34]. In an environment where supply chain interruptions can result in large financial losses, this efficiency is essential. Furthermore, the 50% decrease in contract fulfillment issues highlights how well smart contracts work to build stakeholder confidence, which is essential for supply chain partnerships [31, 38, 33]. There is agreement regarding the benefits of blockchain technology in supply chain operations when comparing these findings with the body of current literature. For example, a comprehensive review found that the decentralized structure and consensus procedures of blockchain greatly reduce the risks of fraud and data manipulation [9]. Additionally, a growing market need for ethical supply chain processes is seen in the 62% of customers who favor businesses that exhibit transparency [34], which emphasizes the necessity for stakeholders to embrace cutting-edge solutions like smart contracts [39]. There are significant practical ramifications for supply chain participants; businesses that use smart contracts can increase customer happiness and trust in addition to operational efficiency [40, 41]. According to the literature, businesses hoping to stay competitive in a global market that is becoming more complex must embrace blockchain technology as a required progression rather than just a trend [42-44, 46, 47]. As a result, the study's conclusions add to the continuing discussion on how important technology is to supply chain management's future.The results of this study highlight the transformative potential of smart contracts in addressing common supply chain management issues, particularly those related to operational efficiency and transparency. The documented 30% increase in operational efficiency aligns with previous research emphasizing how blockchain technology can expedite processes and reduce transaction times [34]. This efficiency is critical in an environment where supply chain disruptions can lead to significant financial losses. Furthermore, the 50% reduction in contract fulfillment disputes illustrates the effectiveness of smart contracts in building stakeholder trust, which is vital for successful supply chain partnerships [31, 38, 33].

Comparing these findings with existing literature reveals a consensus on the advantages of blockchain technology in supply chain operations. For instance, a comprehensive review indicates that the decentralized structure and consensus mechanisms of blockchain significantly mitigate risks of fraud and data manipulation [9]. Additionally, the growing consumer preference for transparent supply chains—evidenced by the 62% of customers favoring businesses that exhibit transparency [34] highlights the necessity for stakeholders to adopt innovative solutions like smart contracts [39].

The practical implications for supply chain participants are substantial; businesses leveraging smart contracts can enhance customer satisfaction and trust alongside operational efficiency [40, 41]. The literature suggests that organizations aiming to remain competitive in an increasingly complex global market must view blockchain technology as an essential evolution rather than a passing trend [42-44]. Consequently, the findings of this study contribute to the ongoing discourse on the critical role of technology in shaping the future of supply chain management.

In the context of food safety, Tian [21] and Caro et al. [22] demonstrate that blockchain-based traceability systems can significantly improve transparency and accountability, which are vital for ensuring food safety. Kamilaris et al. [23] also support this notion, indicating that the adoption of blockchain in agriculture enhances traceability and efficiency, thereby addressing concerns related to food supply chains. However, the adoption of these technologies is not without challenges. Sacala, et al. [46] and Kouhizadeh et al. [26] identify barriers such as technological complexity and regulatory issues that hinder the widespread implementation of blockchain in sustainable supply chains. Despite these challenges, Groschopf et al. [27] propose that smart contracts can contribute to the economic and social development of supply chains, suggesting a pathway for overcoming these barriers. Recent studies, such as those by Alqarni et al. [28] and Bottoni et al. [29], reinforce the notion that blockchain and smart contracts enhance transparency, traceability, and collaboration within supply chains. These findings collectively underscore the potential of blockchain technology and smart contracts to revolutionize supply chain management by improving efficiency, trust, and accountability, while also highlighting the need for addressing existing barriers to adoption.

5. Conclusion

The substantial benefits of using smart contracts in supply chain management have been emphasized by this study, especially in terms of improving operational effectiveness and transparency. According to the research, companies that use smart contracts can increase operational efficiency by up to 30% and decrease contract fulfillment conflicts by 50%. These results highlight how smart contracts, which automate transactions and offer real-time operational visibility, have the

potential to revolutionize conventional supply chain procedures. Additionally, the need for businesses to adopt cutting-edge technologies like smart contracts is highlighted by the growing consumer need for transparency, which is demonstrated by the 62% of consumers who prefer organizations that exhibit responsibility. A number of suggestions can be made to help supply chain management successfully implement smart contracts. First and foremost, companies want to fund training and development initiatives to give their employees the know-how to comprehend and successfully apply blockchain technology. In order to ensure interoperability across various platforms and systems, stakeholders must also work together to create standardized frameworks and protocols that regulate the use of smart contracts. This cooperative strategy can assist in reducing possible integration and scaling issues. Since the current literature frequently ignores these important factors, future research should concentrate on examining the organizational requirements and sustainability consequences of smart contracts. It would also be beneficial to look at how the deployment of smart contracts affects supply chain resilience and adaptability over the long run. Furthermore, empirical research looking at how smart contracts are really used in different industries may confirm their efficacy and reveal implementation best practices. Future studies can advance a more thorough comprehension of the function of smart contracts in contemporary supply chain management by tackling these topics.

Conflict of interest

No conflict of interest is declared by tehe authors. In addition, no financial support was received.

Author contributions

Study Design, HSJ, AB, AAA; Data Collection, MKI, HSJ; Statistical Analysis, AB, AAA; Data Interpretation, AAA, MKI, AB; Manuscript Preparation, HSJ, MKI, AB, AAA; Literature Search, AAA. All authors have read and agreed to the published version of the manuscript.

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